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Review on Available Information on Waves in the DanWEC Area

(DanWEC Vaekstforum 2011)

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Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

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ISSN 1901-726X
DCE Technical Report No. 135

AALBORG UNIVERSITY
Department of Civil Engineering

Aalborg University
Department of Civil Engineering
Water and Soil

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by

Lucia Margheritini

January 2012

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Published 2011 by
Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57,
DK-9000 Aalborg, Denmark

Printed in Aalborg at Aalborg University

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Preface

The Danish Wave Energy Centre (DanWEC) has been established in 2009 because of participated desire to market the trial wave energy projects which are already in Hanstholm and others to come. The DanWEC is a part of Hanstholm harbour in the North-West of Denmark.

The Center will contribute at creating a local base for knowledge, education and possibly a workplace which will be leased out to trial projects. It is therefore likely that different developers will deploy their wave energy devices during the next years in this location and therefore detailed knowledge on a number of environmental and physical parameter is necessary.

The review of the available information on wave data in the DanWEC area presented in this document has been prepared by Lucia Margheritini (lm@civil.aau.dk), Post.Doc at the Department of Civil Engineering at Aalborg University who was involved in previous wave climate studies at Hanstholm location. The report should function as an assessment of the existing documents and present knowledge on wave conditions and data at the DanWEC location.

The present report has been prepared under the project No. 834101 "DanWEC Vaekstforum 2011", task 1: "Collection and presentation of wave data basis from the DanWEC site at the Port of Hanstholm".

Responsible	Version	Date	Comment
LM	0.1	12/06/2012	Correction eq 6 (number) Improved tables 6 and 7

Contents

INTRODUCTION

In connection to the establishment of the Danish Wave Energy Center (DanWEC) in 2009, extensive and comprehensive knowledge on the wave condition at location is desirable. This report is a review of the existing information on available wave data and wave statistics in Hanstholm area. The second last chapter includes suggestion for possible future investigations in order to improve the existing knowledge on the wave conditions.

The data available are from the Hanstholm buoy 3110, (approximately 2 km in front of the harbour entrance), UTM32N Euref89 coordinates: 474 700 E 6 332 100 N, at 17.5 m water depth. The data from the Harbour (Hanstholm buoy) are depth limited. The station is present since 1998 and therefore data available from the Harbour cover the period from 1998 up to today. Nevertheless, the buoy was changed in 2005 and the generated files do not present exactly the same time intervals.

The data from 1998 up to 2005 includes identification number, date (yyyy-month-day), time (00:00) and average H_{m0} [m], H_{max}[m], average T_z [s] and T_p [s] calculated over 20 minutes. The data from 2005 up to today is in the same format but the averages are calculated over 30 minutes instead.

Alternatively wave data can also be obtained from the NOAA WaveWatch III hindcast model at grid point 8°E; 57.5°N, (approximately at 70 km in front of Hanstholm). In the following chapter the main results are summarized.

Finally, the existing harbor was inaugurated in 1967 therefore possibly information on the wave condition dating back to the construction time might be available.

WAVE CONDITIONS

The scatter diagram is presented in terms probability of occurrence for events characterized by designed intervals of H_{m0} and T_{m01} (first column and raw respectively), (Table 1). The data are from the period 01/11/05-25/2/09 from Hanstholm (buoy 3110, approximately 2 km in front of the harbour entrance), UTM32N Euref89 coordinates: 474 700 E 6 332 100 N, at 17.5 m water depth [1, 2, 6, 7]. The raw data are H_{m0} and T_{m01} calculated over 30 minute intervals:

$$H_{m0} = 4 \cdot \sqrt{m_0} \quad \textit{[Equation 1]}$$

$$T_{m01} = \frac{m_0}{m_1} = \frac{1}{1.055} T_e \quad \textit{[Equation 2]}$$

where:

$m_n = \int_0^{+\infty} f^n \cdot E(f)df$ *= n'th order spectral moment, f = frequency [s^{-1}], S(f) = Spectrum energy density depending on the frequency [m^2s].*

The wave power has been calculated based on the parameterized JONSWAP spectrum:

$$S(f) = \alpha \cdot H_{m0}^2 \cdot f_p^4 \cdot f^{-5} \cdot exp\left[-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right] \cdot \gamma^\beta \quad \textit{[Equation 3]}$$

where:

$\gamma = peack\ Enhancemet$

$$\alpha = \frac{0.0624}{0.230 + 0.0336 \cdot \gamma - \frac{0.185}{1.9 + \gamma}}$$

$$\beta = exp\left(-\frac{(f-f_p)^2}{2 \cdot \sigma \cdot f_p^2}\right), \qquad \sigma = \begin{cases} 0.07\ for\ f \le f_p \\ 0.09\ for\ f > f_p \end{cases}$$

The wave power is calculated in the assumptions of the Shoaling Theory taking into consideration the water depth (Table 2 and Table 3):

$$P_{wave} = EC_g = \frac{1}{8}\rho g H_{m0}^2 \left(\frac{1}{2} + \frac{kh}{\sinh(2kh)}\right) \cdot C \quad \textit{[Equation 4]}$$

Being:

ρ=1020 [kg/m^3] the water density and *g*=9.82 [m/s^2] the acceleration of gravity.

E=energy in one wave par surface area, *Cg*=wave group velocity [m/s], *C* = wave celerity [m/s]

k=wave number related to the wave length and *h* is the water depth [m].

Table 1. Scatter diagram (probabilities) for Hanstholm buoy, DanWEC.

Hm0 - Tm01	[0-2.25)	[2.25-2.75)	[2.75-3.25)	[3.25-3.75)	[3.75-4.25)	[4.25-4.75)	[4.75-5.25)	[5.25-5.75)	[5.75-6.25)	[6.25-6.75)	[6.75-7.25)	[7.25-7.75)	[7.75-8.25)	[8.25-8.75)	[8.75-9.25)	[9.25-9.75)	[9.75-10.25)	[10.25-10.75)	[10.75-11.25)	[11.25-11.75)	[11.75-20.25)
[0-0.25)	0.0002	0.0005	0.0045	0.0081	0.0090	0.0048	0.0016	0.0004	0.0003	0.0002	0.0000	0.0001	0.0000	-	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004	0.0078
[0.25-0.75)	0.0002	0.0029	0.0210	0.0613	0.0677	0.0483	0.0316	0.0172	0.0081	0.0029	0.0016	0.0014	0.0008	0.0007	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0032
[0.75-1.25)	-	0.0002	0.0024	0.0161	0.0683	0.0815	0.0621	0.0429	0.0165	0.0056	0.0017	0.0004	0.0001	-	-	-	-	-	0.0000	-	0.0006
[1.25-1.75)	-	-	0.0001	0.0010	0.0099	0.0524	0.0608	0.0350	0.0156	0.0049	0.0031	0.0006	0.0002	0.0001	0.0000	-	-	-	-	-	0.0002
[1.75-2.25)	-	-	-	0.0003	0.0005	0.0031	0.0365	0.0420	0.0181	0.0046	0.0017	0.0007	0.0004	0.0003	0.0002	0.0001	0.0000	-	-	-	-
[2.25-2.75)	-	-	-	-	0.0000	0.0003	0.0013	0.0213	0.0220	0.0059	0.0012	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	-	-	-	-
[2.75-3.25)	-	-	-	-	-	0.0003	0.0002	0.0008	0.0102	0.0127	0.0023	0.0007	0.0004	0.0002	0.0002	0.0001	0.0001	0.0000	0.0000	-	-
[3.25-3.75)	-	-	-	-	-	0.0000	0.0002	0.0003	0.0002	0.0043	0.0045	0.0010	0.0003	0.0002	0.0001	0.0000	-	0.0001	0.0000	-	-
[3.75-4.25)	-	-	-	-	-	-	-	0.0001	0.0001	0.0001	0.0020	0.0022	0.0002	0.0001	0.0000	-	-	-	-	-	-
[4.25-4.75)	-	-	-	-	-	-	-	0.0000	0.0001	0.0000	0.0000	0.0007	0.0010	0.0003	0.0001	-	-	-	-	-	-
[4.75-5.25)	-	-	-	-	-	-	-	-	0.0002	0.0001	0.0000	-	0.0003	0.0003	0.0002	0.0001	-	-	-	-	-
[5.25-5.75)	-	-	-	-	-	-	-	0.0000	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	-	-	-	-	-
[5.75-6.25)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-
[6.25-6.75)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-

Table 2. Pwave for Hanstholm buoy, DanWEC.

Hm0 - Tm01	1.125	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	16
0.125	0.0093	0.0206	0.0247	0.0291	0.0338	0.0391	0.0448	0.0507	0.0565	0.0621	0.0672	0.0720	0.0764	0.0804	0.0840	0.0872	0.0902	0.0928	0.0952	0.0974	0.1101
0.5	0.1482	0.3294	0.3960	0.4654	0.5411	0.6253	0.7164	0.8107	0.9038	0.9928	1.0760	1.1526	1.2225	1.2860	1.3436	1.3955	1.4425	1.4850	1.5235	1.5583	1.7614
1		1.3175	1.5838	1.8615	2.1645	2.5011	2.8657	3.2426	3.6152	3.9713	4.3039	4.6103	4.8901	5.1442	5.3742				6.0938		7.0458
1.5			3.5636	4.1884	4.8701	5.6275	6.4479	7.2959	8.1341	8.9354	9.6838	10.3730	11.0030	11.5740	12.0920						15.8530
2				7.4461	8.6580	10.0050	11.4630	12.9700	14.4610	15.8850	17.2160	18.441	19.56	20.577	21.497	22.329	23.0800				
2.5					13.5280	15.6320	17.9110	20.2660	22.5950	24.8200	26.9000	28.814	30.563	32.151	33.589	34.888	36.0630				
3						22.5100	25.7920	29.1840	32.5360	35.7420	38.7350	41.493	44.011	46.298	48.368	50.239	51.9310	53.4600	54.8440		
3.5						30.6390	35.1050	39.7220	44.2860	48.6480	52.7230	56.476	59.904	63.016	65.834	68.381		72.7650	74.6490		
4								51.8820	57.8430	63.5400	68.8630	73.765	78.242	82.307	85.987						
4.5								65.6630	73.2070	80.4180	87.1550	93.359	99.024	104.17	108.83						
5									90.3790	99.2820	107.60		122.25	128.6	134.36	139.55					
5.5								98.0890		120.1300	130.1900	139.46	147.93	155.61	162.57	168.86					
6																200.96					
6.5																235.8500					

Table 3. Pwave*Probability for Hanstholm buoy, DanWEC and selected groups for Sea States design.

Hm0 - Tm01	1.125	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	16
0.125	1.801E-06	9.3379E-06	0.000111719	0.000234342	0.00030463	0.0001882	7.3506E-05	2.189E-05	1.586E-05	1.3403E-05	1.453E-06	7.78E-06	3.301E-06	0	7.2552E-06	1.884E-06	3.89481E-06	2.00475E-05	2.46801E-05	4.20745E-05	0.000858443
0.5	3.521E-05	0.00096045	0.008330418	0.028508244	0.0366544	0.0302132	0.02260927	0.0139031	0.0073207 1	0.00291653	0.0016966	0.0016681	0.000977	0.0008611	0.0002612	0.00030143	6.23164E-05	6.41524E-05	3.29078E-05	6.7319E-05	0.005706973
1	0	0.00025612	0.003831553	0.02995545	0.14783456	0.203833	0.17783731	0.1391707	0.0597379	0.02221718	0.0075302 2	0.0018921	0.0004225	0	0	0	0	0	0.000131627	0	0.003956947
1.5	0	0	0.000461846	0.003980681	0.04817923	0.2947703	0.39192135	0.255615	0.1272051	0.04400534	0.0297023	0.0060486 3	0.0019013	0.00125	0.00026119	0	0	0	0	0	0.002739416
2	0	0	0	0.001930041	0.00430132	0.0306875	0.41795283	0.5448991	0.261445	0.07308418	0.0301213	0.0131448	0.0080245 4	0.0057781	0.00417904	0.00289386	0.000997062	0	0	0	0
2.5	0	0	0	0	0.00058441	0.0047271	0.02359968	0.4320577	0.4968401	0.14689563	0.0319574	0.0130701	0.007922	0.0034723 5	0.00145105	0.00150717	0.000778966	0	0	0	0
3	0	0	0	0	0	0.0058346	0.00612822	0.0220632	0.3331187	0.45241083	0.0878515	0.0286801	0.0161609	0.0110005	0.00731329	0.00651102	0.006730301	0.001154743	0.001184638	0	0
3.5	0	0	0	0	0	0.0013236	0.00682446	0.012012	0.0095658	0.2091099	0.2368754	0.054895	0.0181151	0.0122504	0.00853214	0.00295408	0	0.004715202	0.001612429	0	0
4	0	0	0	0	0	0	0	0.006724	0.0074965	0.00823484	0.135358	0.1609268	0.0185904	0.0053335	0.00371466 6	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0.0014183	0.0094877	0.00347408	0.0018826	0.0645302	0.0962519	0.027001	0.01175372	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0.0136654	0.00643351	0.0023242	0	0.0316874	0.0416667	0.02611975	0.0090429	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0.0021187	0	0.00518965	0.0028121	0.0030124	0.0031953	0.0067224	0.00702307	0.018237 7	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00434076	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00509439	0	0	0	0	0

Sea States

Different wave conditions (H_{m0} and T_{m01}) have been grouped in 6+1 cells within the Pwave*Probability diagram (Table 4). The total wave power available at location is 7.1 kW/m. The cells are formed around the highest values of the diagram and have similar total Pwave*Probability (around 1.1 kW, with exception of cell 7 that features a much lower value ~ 0.2 kW). This grouping represents 97.3% of the total available power (Pwave*probability). Based on this division, the 7 sea states for the DanWEC are presented in Table 4, (Fig.1).

Table 4. DanWEC Sea States.

Sea state No.	H_{m0} [m]	T_{m0} [s]	Probability [-]	Pwave*Prob [kW]
1	0.9	4.7	0.545	1.105
2	1.5	5.2	0.182	1.161
3	2	5.5	0.107	1.304
4	2.5	5.9	0.052	1.091
5	3	6.4	0.027	0.896
6	3.8	7.2	0.018	1.048
7	5.2	8.5	0.001	0.167
			TOT	**6.605**

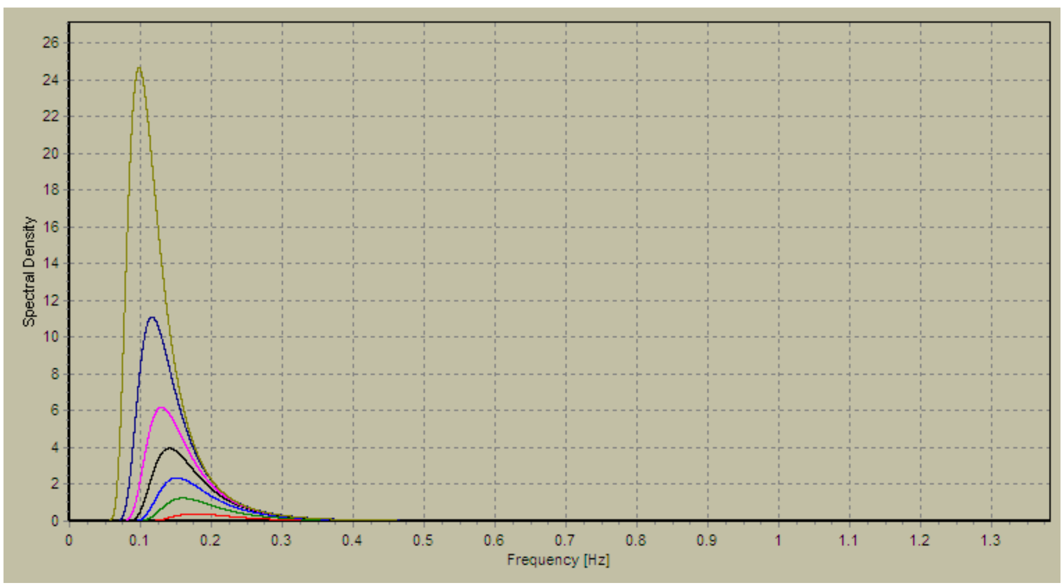

Figure 1. Wave Spectra for the designed sea states.

For the groups 2, 3, 4 and 5 the wave height´s class mark is the middle value of the range; f.ex, H_{m0}=1.5 includes all the waves in the interval = [1.25-1.75) while for groups 1, 6 and 7 they are the result of the weighted average of the wave height class marks on the sum of the Pwave*Probability for each class mark. For all the groups, the period´s class mark is the weighted average of the period´s class mark on the sum of the Pwave*Probability for each class mark. The sea states here presented cover 96.0% of the total available power (93.7% if excluding, sea state No. 7).

EXTREME WAVES

For the extreme wave analysis a longer data set has been used: Hanstholm (buoy 3110; 474 700 E, 6 332 100 N, 17.5 m. water depth. Duration: from 19/5/1998 to 25/2/2009). The data set contained unrealistic wave heights (compared to wave period and water depth) which indicated breaking waves, not correctly measured. Based on the filtered dataset the extreme wave conditions offshore the proposed site, have been determined by:

• Peak over threshold analysis of time series data (7.1 years from 19/05/1998 to 25/06/2005, 77% data return): Selection of 33 storm peaks with Hs > 4.1 m; maximum wave height Hs = 7.09 m.

• Extreme value analysis: Extrapolation of 1:100 years wave height from 33 storm peaks (Weibull fit, shape coefficient k = 1.4, standard deviation 0.757 m, correlation coefficient 0.9924).

The extreme wave analysis resulted in Hs=8.28 m for 100 year return period. In accordance to the standard, the range of the wave peak period Tp is given by:

$$\sqrt{\frac{130H_s}{g}} < T_p < \sqrt{\frac{280H_s}{g}} \qquad \textit{[Equation 5]}$$

The extreme wave conditions for different return periods have been calculated and are presented in Table 5.

Table 5. DanWEC extreme waves.

Return Periods [y]	Significant wave height [m]
1	5.56
2	6.05
5	6.63
10	7.04
20	7.43
50	7.92
100	8.28

Note: The waves at the buoy (data acquisition point) are depth limited and it is therefore not completely realistic that the wave height can be extrapolated as is be done in an extreme value analysis [7] (the physical mechanism does not allow these high waves: by a simple but widely used breaking coefficient d≤H/0.78, with d= water depth at location = 17.5 m, the limit for single wave at the buoy without breaking is H<13.8 m).

WAVE DIRECTION

The Hanstholm wave buoy is not directional therefore a study has been done using additional information from Fjaltring (buoy 2031; 441976 E, 6 259 466 N, 17.5 m. water depth. Available: 11/08/99-25/02/09) and Hirtshals (buoy 1041; 524 559 E, 6 381 744 N, 17 m. water depth. Available: 11/12/91-25/02/09). The angle of the incoming waves in Hanstholm has been interpolated by a vectorial addition of the wave directions in Hirtshals and Fjaltring [6]. In occasions, the vectorial addition could not be executed because the times of the extracted data in the different buoys were not equal. In those cases, a weighed mean has been calculated between the next and the previous recordings from the specific buoy (Fjaltring or Hirtshals buoy) as:

$$DirX_i = Dir\_timeX\_next_i \cdot \left(\frac{timeHa_i - timeX\_prev_i}{timeX\_next_i - timeX\_prev_i} \right) + $$
$$+ Dir\_timeX\_prev_i \cdot \left(1 - \frac{timeHa_i - timeX\_prev_i}{timeX\_next_i - timeX\_prev_i} \right) \quad \textit{[Equation6]}$$

Where:

DirXi is the direction of the waves in the location (Hirtshals or Fjaltring) in the time i (time from Hanstholm).

Dir_timeX_nexti is the direction of the waves in the location (Hirtshals or Fjaltring) in the successive time to time i from Hanstholm.

timeX_nexti is the time of the location successive to the time i from Hanstholm.

timeHai is the time i from Hanstholm.

timeX_previ is the time of the location previous to the time i from Hanstholm.

Dir_timeX_previ is the direction of the waves in the location (Hirtshals or Fjaltring) in the previous time to time i from Hanstholm.

The operational wave conditions offshore Hanstholm Harbour are summarized in Fig. 2. The predominant wave direction is W to WNW (258° to 305°).

Prevailing and dominant wave directions are West-North-West and West.

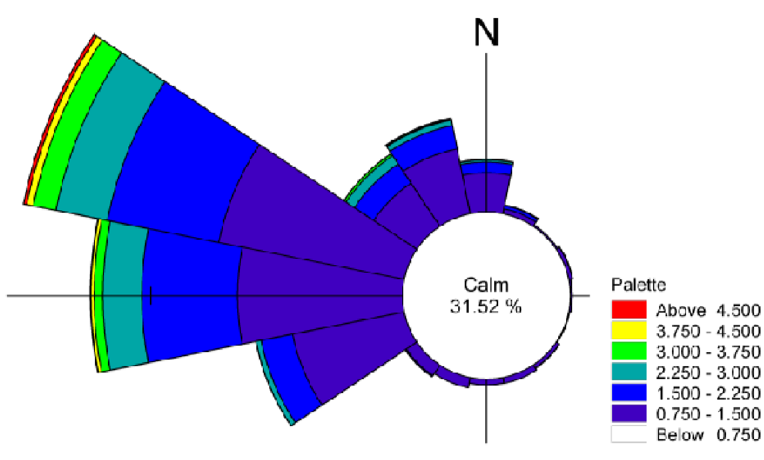

Figure 2. DanWEC wave rose.

NEAR SHORE WAVE CONDITIONS

The bathymetry at location comprehends the area going from the Hanstholm buoy to shore, therefore including water depth from 17.5 m to 0 m. Transformation of waves from offshore to three selected close-to-shore locations (Fig. 3) has been done using the computer model MILDwave [1-5] for specific combinations of H_{m0}, T_p and wave direction representative of offshore operational and extreme conditions. Transformation matrices are presented in Table 6 and 7, with indication on individual coordinates for the selected points.

- The waves are modelled as long crested irregular waves, characterized by a JONSWAP Spectrum (γ = 3.3) defined by significant wave height H_{mo} and T_p.
- The wave directions West (270°), North-West (315°) and North (0°) have been simulated.
- The operational conditions were calculated for water level at +0.00 m, while the extreme wave conditions for a water level at +1.20 m.

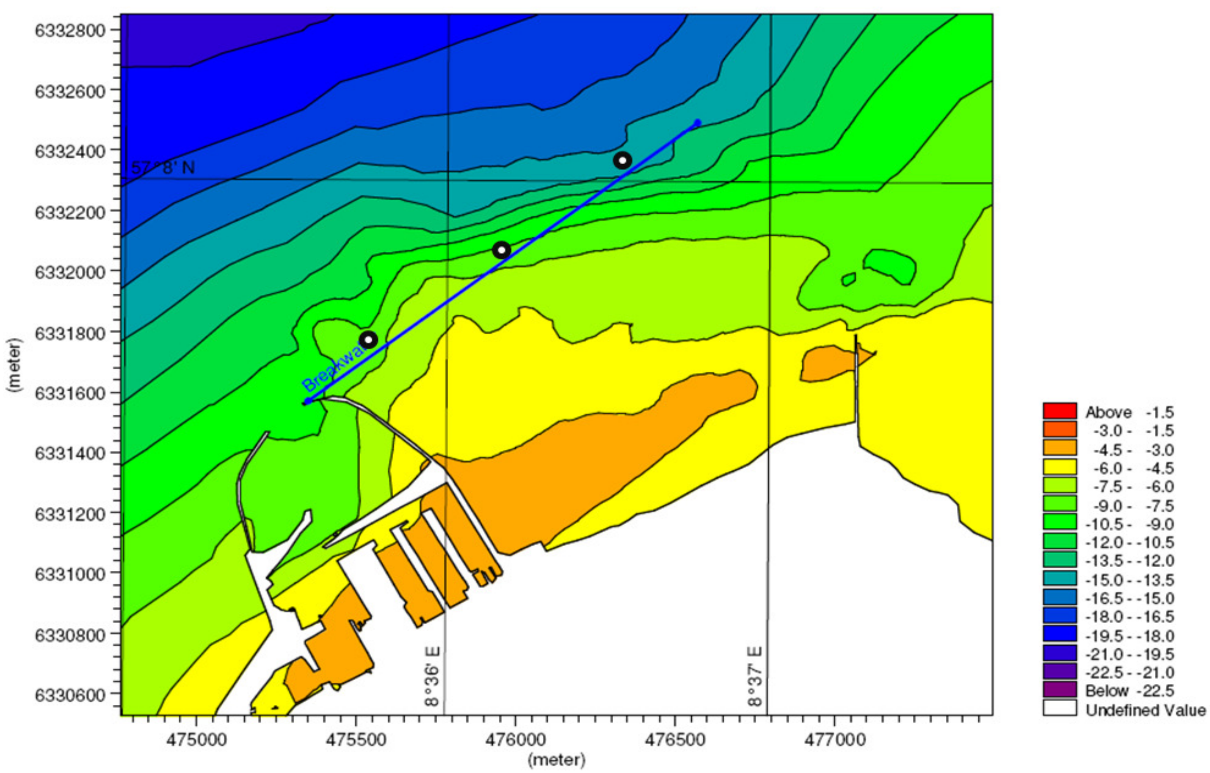

Figure 3. DanWEC bathymetry and highlighted close to shore selected points for the transformation of offshore waves.

The H_{m0} contour plot is presented for the most critical of the operational conditions in front and around the existing harbour (Fig 4-10). The white spots indicate the locations of the wave gauges arrays, while the red spot is “Hanstholm buoy 3110”.

Table 6. Transformation matrix offshore/near-shore operational wave conditions, DanWEC area

Target values at the buoy			474700 E 6332100 N			476254 E 6332100 N			475557 E 6331689 N		476950 E 6332404 N	
Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Hm0 [m]	Tp [s]
0.90	5.40	270 (West)	0.899	5.40	271.00	0.633	5.40	279.00	0.880	5.40	0.736	5.40
0.90	7.80		8.877	7.80	273.00	0.584	7.80	298.00	1.122	7.80	0.557	7.80
1.50	5.70		1.502	5.70	271.00	0.958	5.70	285.00	0.975	5.70	0.927	5.70
1.50	7.30		1.500	7.30	283.00	1.006	7.30	298.00	1.861	7.30	1.067	7.30
2.00	5.90		1.990	5.90	279.00	1.435	5.90	288.00	1.015	5.90	2.009	5.90
2.00	7.00		1.977	7.00	282.00	1.339	7.00	290.00	2.235	7.00	1.376	7.00
2.50	7.10		2.496	7.10	280.00	1.638	7.10	291.00	2.825	7.10	1.787	7.10
3.00	7.60		2.995	7.60	283.00	2.050	7.60	300.00	3.260	7.60	2.075	7.60
3.50	8.20		3.500	8.20	285.00	2.533	8.20	300.00	3.321	8.20	2.399	8.20
4.40	9.10		4.405	9.10	280.00	3.338	9.10	302.00	2.917	9.10	2.764	9.10
0.90	5.20	315 (North-West)	0.902	5.20	315.00	0.825	5.20	318.00	0.733	5.20	0.837	5.20
1.50	5.70		1.499	5.70	315.00	1.358	5.70	319.00	1.203	5.70	1.369	5.70
2.00	5.90		2.013	5.90	315.00	1.895	5.90	319.00	1.693	5.90	1.867	5.90
2.50	7.10		2.498	7.10	315.00	2.451	7.10	322.00	2.450	7.10	2.354	7.10
3.50	8.10		3.506	8.10	317.00	3.281	8.10	327.00	2.953	8.10	3.339	8.10
0.90	5.10	0 (North)	0.904	5.10	1.00	0.832	5.10	359.00	0.641	5.10	0.875	5.10
1.50	5.60		1.508	5.60	1.00	1.406	5.60	357.00	0.994	5.60	1.423	5.60

Table 7. Transformation matrix offshore/near-shore extreme wave conditions, DanWEC area

Target values at the buoy			474700 E 6332100 N			476254 E 6332100 N			475557 E 6331689 N		476950 E 6332404 N		
Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Theta [˚]	Hm0 [m]	Tp [s]	Hm0 [m]	Tp [s]	Theta [˚]
7.00	11.90	315 (North-West)	7.0	11.90	321	5.6	11.90	329	4.9	11.90	6.3	11.90	316
8.50	13.10		8.6	13.10	322	5.7	13.10	329	5.0	13.10	6.4	13.10	328
0.90	5.10	0 (North)	7.0	11.90	3	5.8	11.90	359	4.3	11.90	6.3	11.90	348
1.50	5.60		8.5	13.10	2	5.9	13.10	348	4.4	13.10	6.4	13.10	348

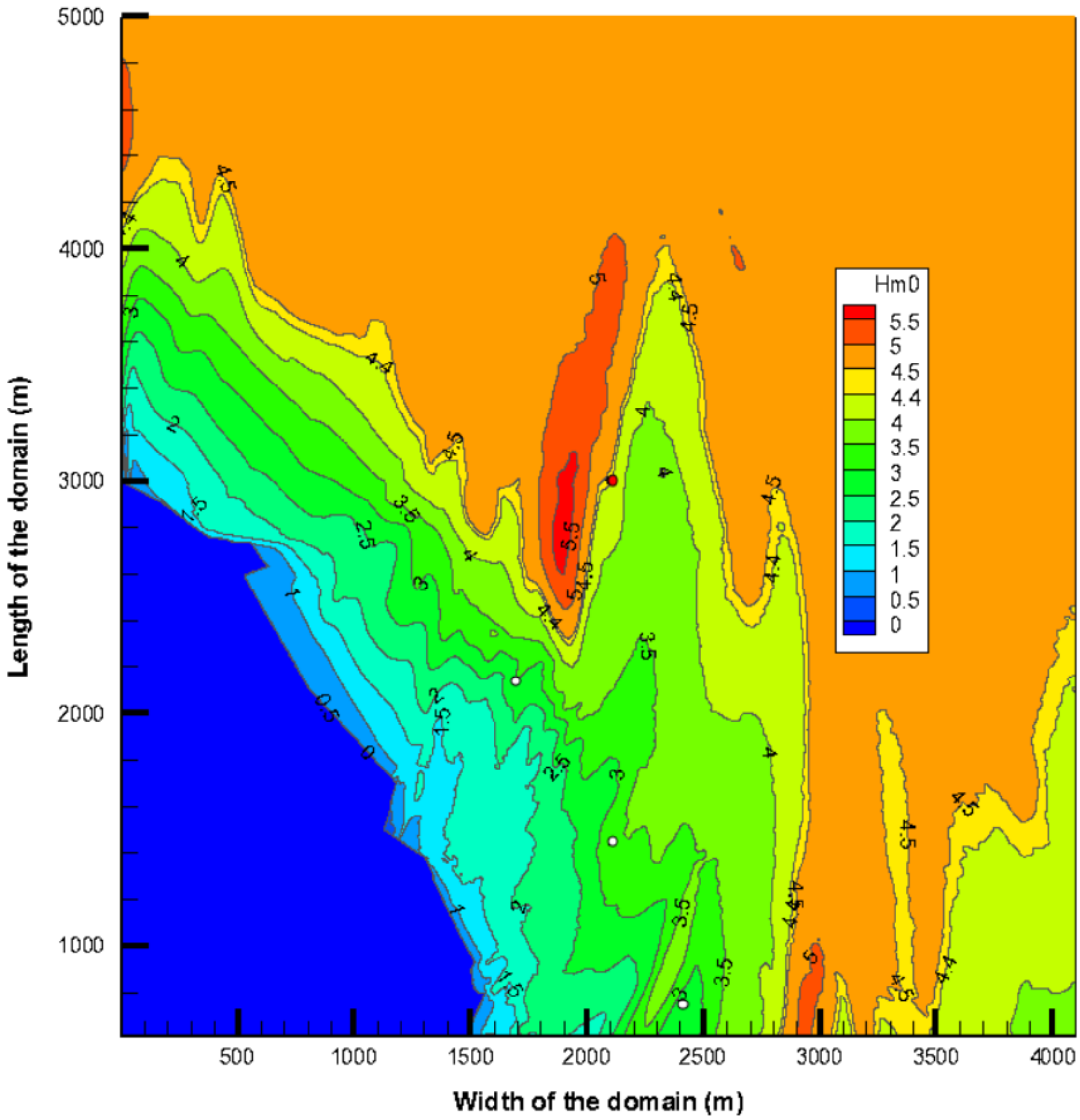

Figure 4. W, Hm0 = 4.4 m, Tp = 9.1 s

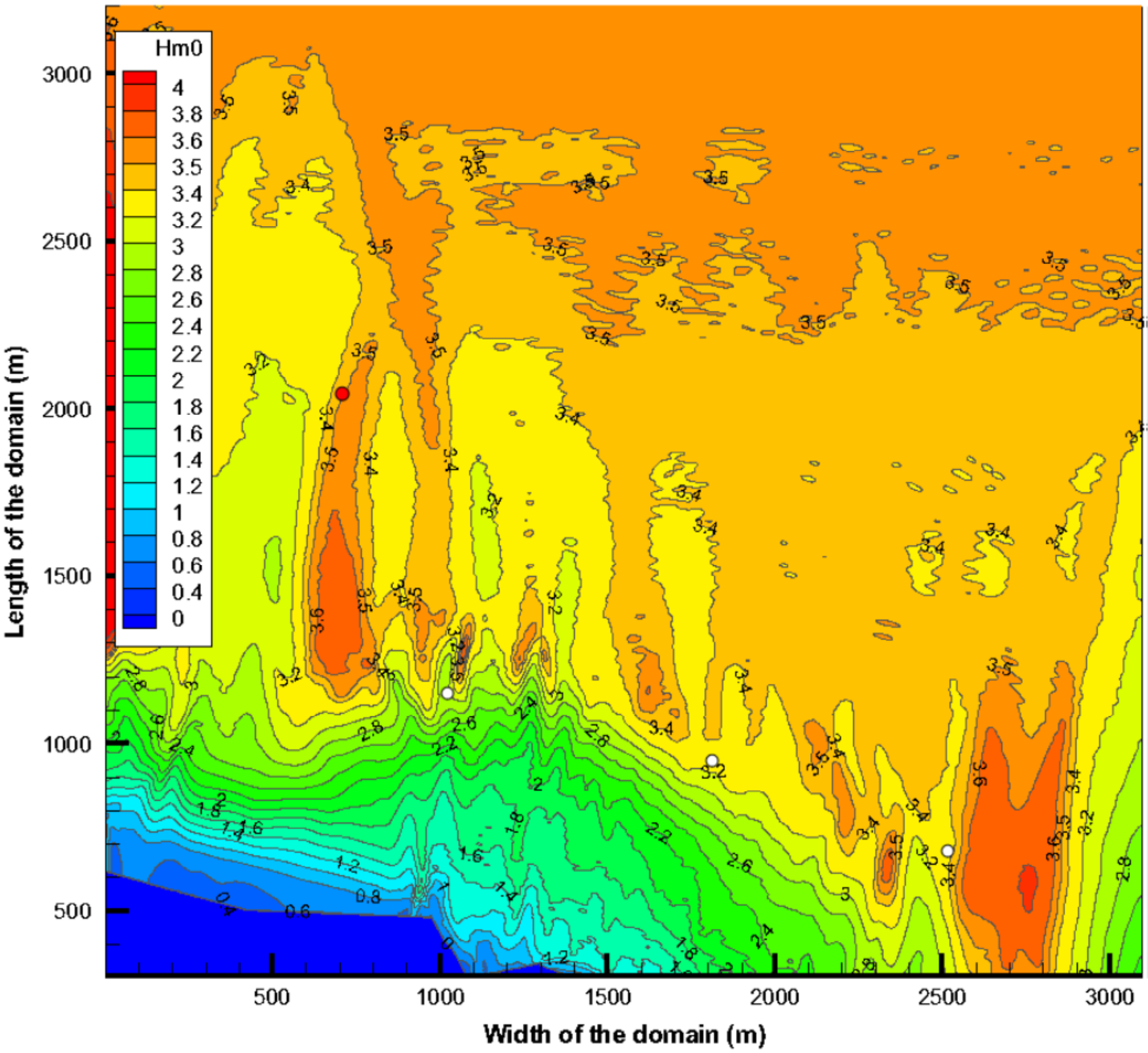

Figure 5. NW, Hs=3.5 m, Tp=8.1 s)

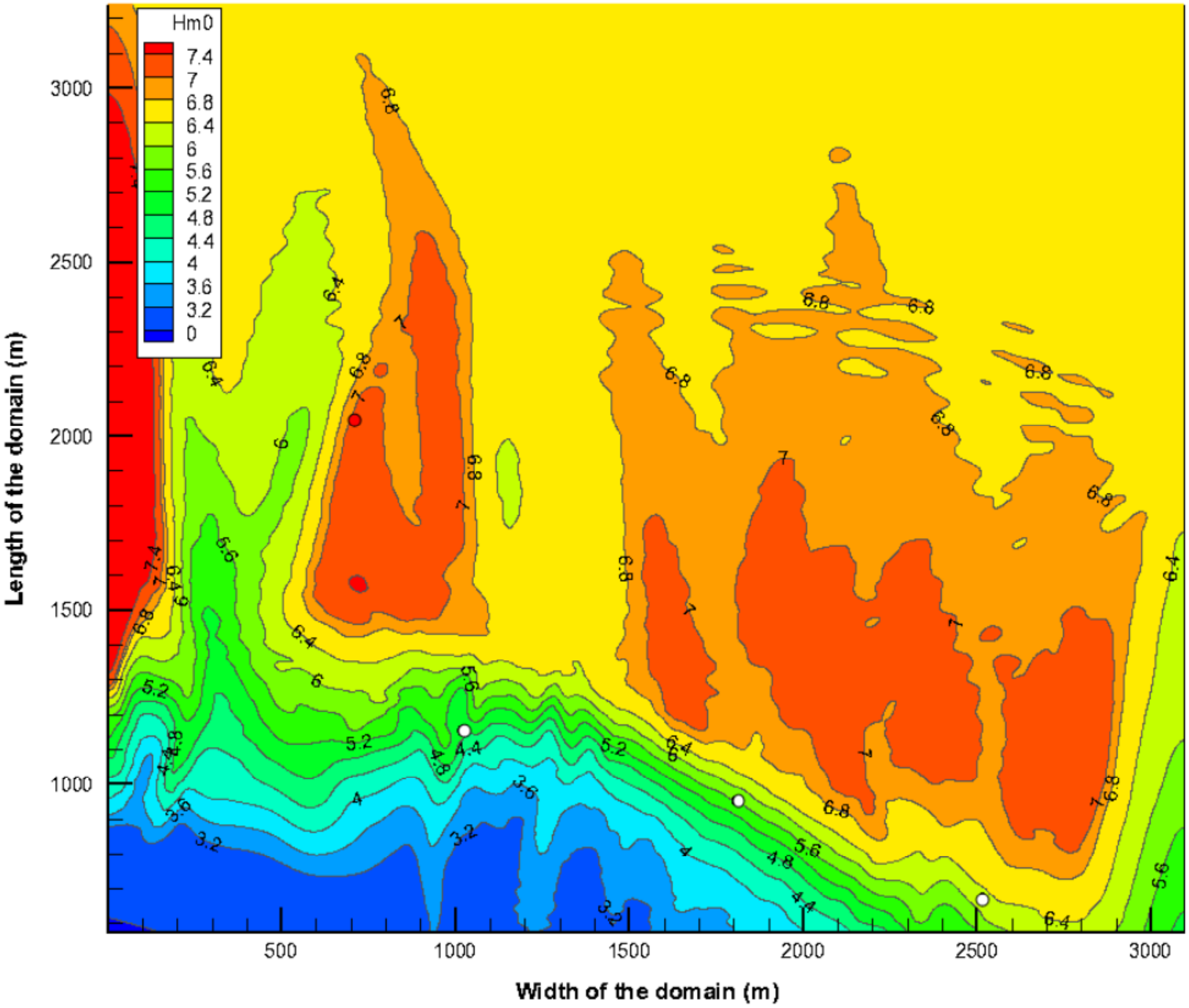

Figure 6. NW, Hm0 = 7.0 m, Tp=11.9 s

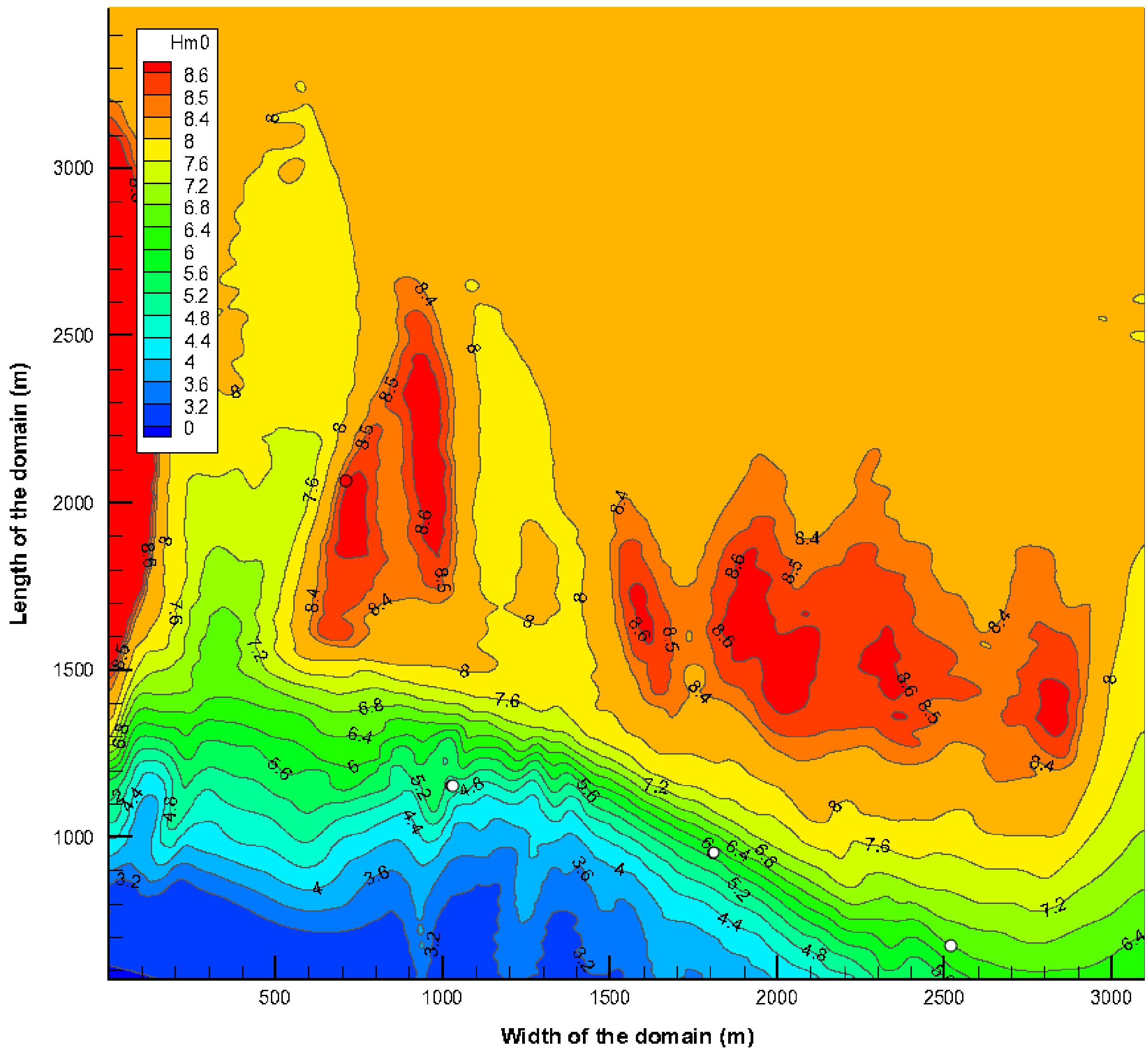

Figure 7. NW, Hm0 = 8.5 m, Tp=13.1 s

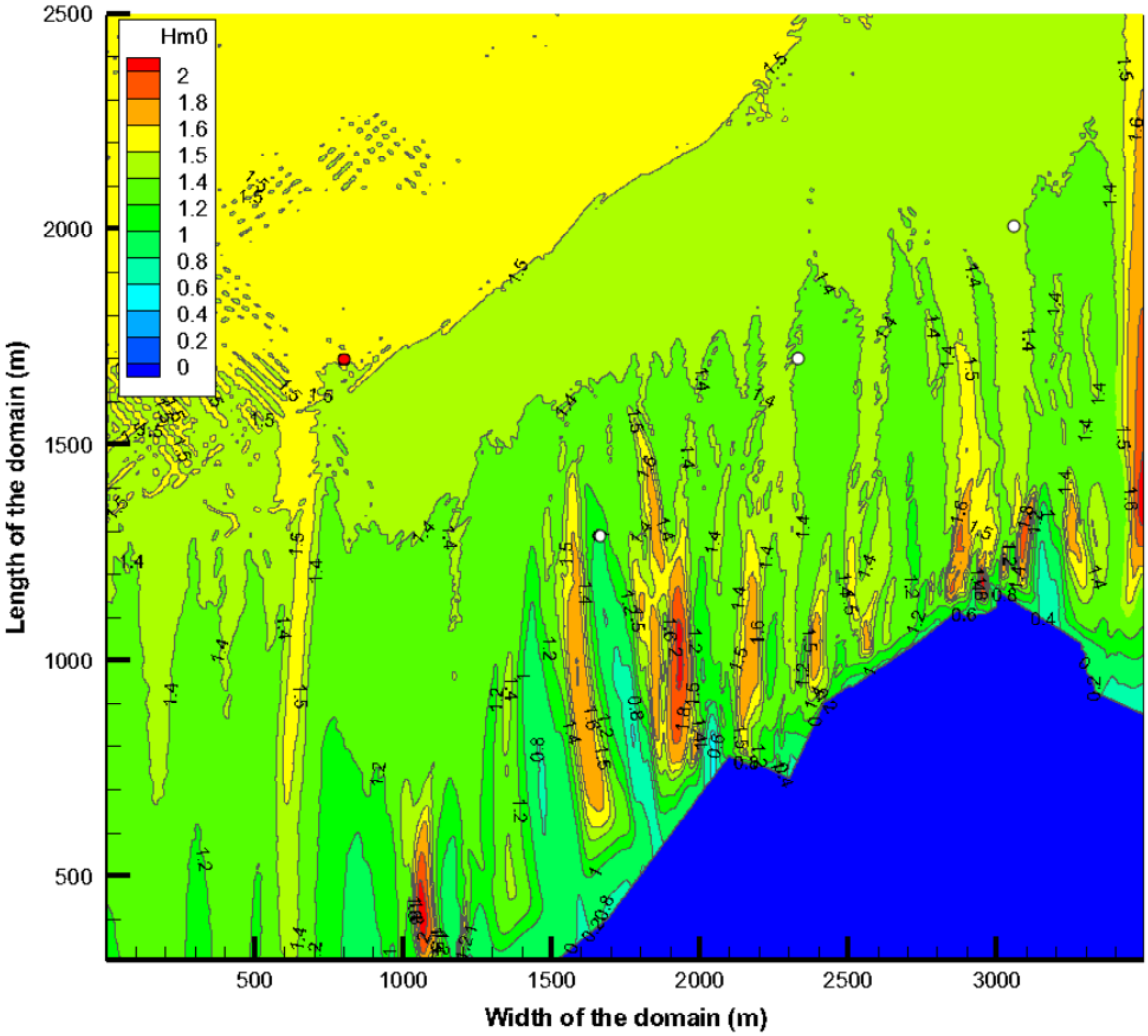

Figure 8. N, Hm0 = 1.5 m, Tp = 5.6 s

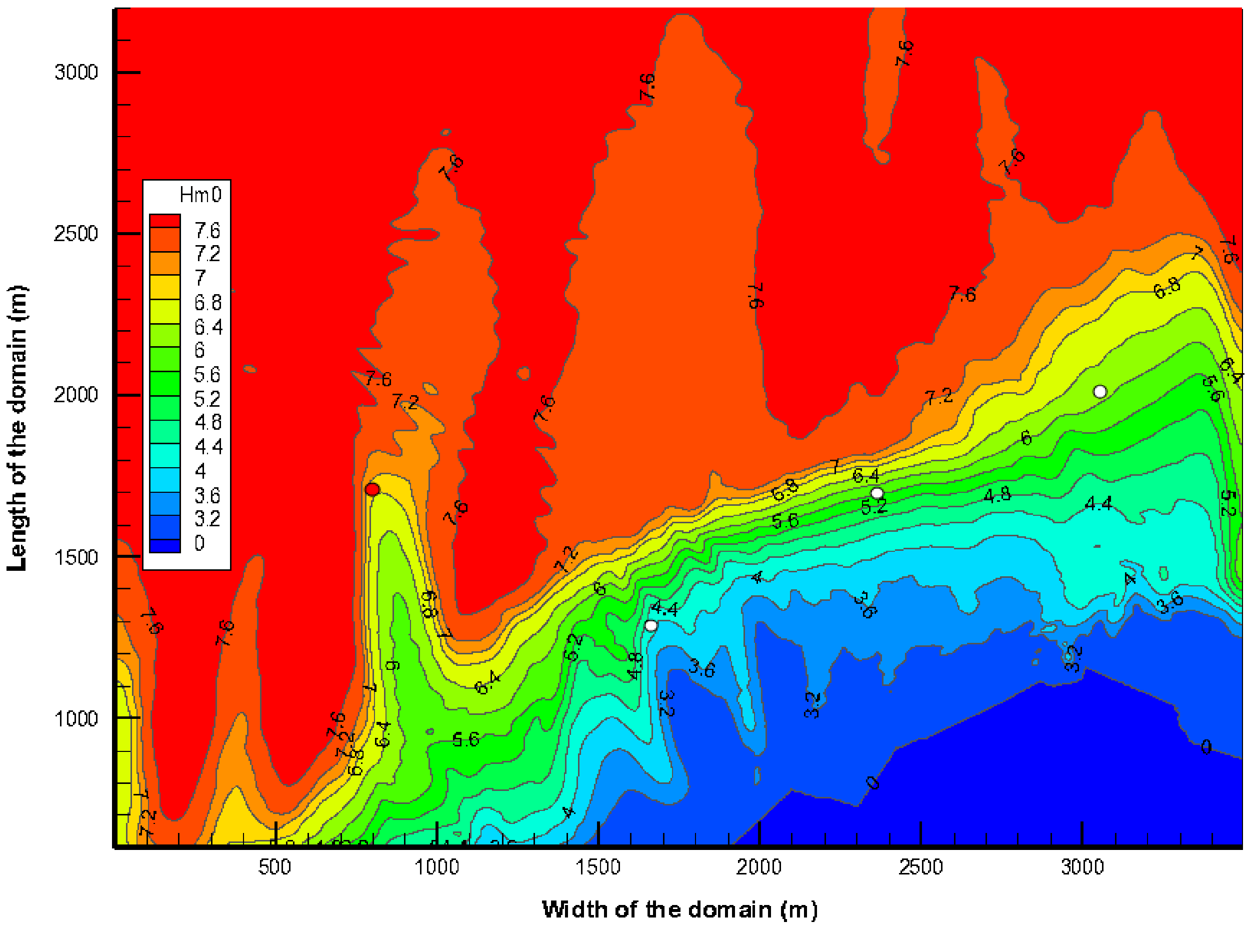

Figure 9. N, Hm0 = 7.0 m, Tp=11.9 s

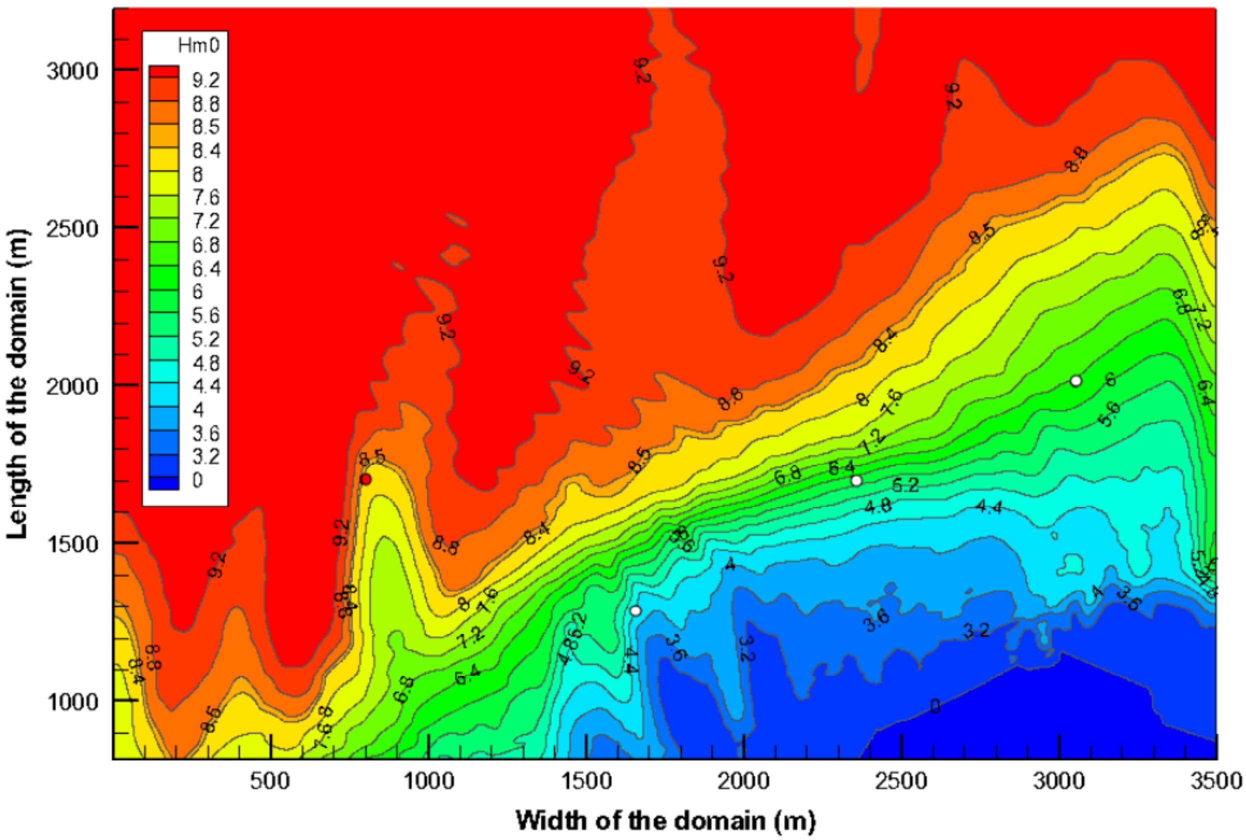

Figure 10. N, Hm0 = 8.5 m, Tp=13.1 s

FUTURE WORK

Future work for the analysis of wave data in the DanWEC area could comprehend the following points:

1) To merge all the available wave data from the Hanstholm buoy (1998-2005 set and 2005 up to today set) provided by the Hanstholm Harbour and to re-calculate the scatter diagrams and extreme waves (Table 8).
2) To study the seasonality of wave conditions in the DanWEC area.
3) To perform a comprehensive study on wave directionality using longer data record.
4) To perform a study on the possible correlation between wind and waves.
5) To compare the results for extreme waves obtained with Hantholm buoy data and data based on the NOAA WaveWatch III hindcast model at grid point 8°E; 57.5°N.
6) To organization a close-to-shore wave energy map for possible future locations for wave energy devices installation.

Table 8. Available data from the Hanstholm buoy, used (blue) and not yet used (gray) data.

Wave conditions	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012

Extreme waves	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012

CONCLUSIONS

Available data from Hanstolm Harbour cover the years from 1998 to today. Based on data from 2005 and 2009 scatter diagrams have been generated for the DanWEC location.

Wave climate at the buoy is 7.1 kW/m; the power was calculated based on the Shoaling Theory being the buoy at 17.5 m water depth and depth limited.

6+1 sea states for the buoy have been designed covering 96.0% of the total available power.

The significant wave height for 100 y return period is 8.28 m.

Indications on wave direction is also available but could be improved.

Transformation matrix for offshore to close-to-shore waves are provided for a limited number of representative operational and extreme conditions.

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